

A STABLE MASSIVE CHARGED PARTICLE

G. Rajasekaran

Institute of Mathematical Sciences, Chennai 600113, India
and
Chennai Mathematical Institute, Siruseri 603103, India
e-mail: graj@imsc.res.in

Abstract : We consider the possibility of the existence of a stable massive charged particle by a minimal extension of the standard model particle content. Absolute stability in the case of singly charged particle is not possible if the usual doublet Higgs exists, unless a discrete symmetry is imposed. But a doubly charged particle is absolutely stable.

Standard Model (SM) of high energy physics based on the gauge group $SU(3) \times SU(2) \times U(1)$ has quarks which transform nontrivially under all the three factor groups $SU(3)$, $SU(2)$ and $U(1)$ while leptons transform nontrivially under two of them: $SU(2)$ and $U(1)$. Is it possible to have a fermion that transforms nontrivially under $U(1)$ only? The answer is yes. It will be an electrically charged fermion that does not have weak decays or strong interactions. If in addition it is stable, it will be an interesting particle. It is remarkable that SM allows such a possibility and the aim of this note is to point this out.

In the SM, the electrical charge Q is given by

$$Q = I_3 + \frac{Y}{2}$$

where I_3 and Y are the usual $SU(2)$ and $U(1)$ quantum numbers respectively. We now envisage a fermion ψ which is a singlet under $SU(3)$ and $SU(2)$. Since Y is arbitrary, we consider two possibilities: (1) $Y = -2$, $Q = -1$ and $Y = -4$, $Q = -2$.

All we have to do is to add the following piece L_ψ to the Lagrangian density of SM:

$$L_\psi = i\bar{\psi}\gamma_\mu(\partial_\mu - i\frac{g_1}{2}YB_\mu)\psi - m\bar{\psi}\psi$$

where B_μ is the $U(1)$ gauge field, g_1 is its coupling constant and Y is the hypercharge of ψ . We take both the helicity components ψ_L and ψ_R to have the same Y . Note that the mass term $m\bar{\psi}\psi$ is allowed and hence m is arbitrary. After the breaking of $SU(2) \times U(1)$, B_μ can be reexpressed in terms of A_μ and Z_μ :

$$B_\mu = \cos\theta A_\mu + \sin\theta Z_\mu$$

$$\tan\theta = \frac{g_1}{g_2}$$

$$g_2 \sin\theta = e$$

where θ is the usual electroweak mixing angle. Hence L_ψ becomes

$$L_\psi = i\bar{\psi}\gamma_\mu(\partial_\mu - ieQA_\mu - iQg_2\tan\theta\sin\theta Z_\mu)\psi - m\bar{\psi}\psi.$$

Thus we see that the only couplings involving ψ are $\bar{\psi}\gamma_\mu\psi A_\mu$ and $\bar{\psi}\gamma_\mu\psi Z_\mu$ and so $\psi\bar{\psi}$ pair can be produced in high energy collisions of e^+e^- , $q\bar{q}$, qq etc, via virtual γ or Z . Standard formulae for the production of massive charged fermions in leptonic and hadronic colliders exist in the literature. To prevent the decay of the Z boson into $\bar{\psi}\psi$, we impose the bound:

$$m > \frac{m_Z}{2}.$$

What about the Higgs sector? We consider case (1) first. The only invariant Higgs coupling is of the type $f \bar{l}_L \phi^c \psi$, where l_L is any one of the three left-handed leptonic doublets consisting of a neutrino and a charged lepton and ϕ^c is the charge-conjugate of the Higgs doublet (ϕ^0, ϕ^-) . The nonvanishing vacuum expectation value $\langle \phi^0 \rangle = v$ leads to non-diagonal mass terms mixing ψ with e, μ and τ . Hence in the charged lepton sector we have a 4x4 mass matrix which has to be diagonalized to get the physical fermions e, μ, τ and ψ . Actually the Lagrangian given above must include off-diagonal mass terms connecting ψ with all the right-handed charged leptons (which are present even without Higgs and its vacuum expectation value). These also must be included in the diagonalization process.

In the 3x3 submatrix of the e, μ, τ sector, the physical Higgs boson H can be added to v , but that is not true of the full 4x4 mass matrix. Hence although the diagonalization of the mass matrix eliminates the off-diagonal flavour-changing couplings such as $\mu e H$, the couplings $\psi e H, \psi \mu H$ and $\psi \tau H$ remain. The real decays of ψ into H and a charged lepton can be prevented by imposing the bound $m < m_H + m_\tau$. However the decay of ψ into a photon and a charged lepton through one loop diagrams arising from the off-diagonal couplings such as $\psi e H$ cannot be forbidden, thus making ψ unstable.

We invoke a discrete symmetry Z_2 and assign $Z_2 = -1$ for ψ and $+1$ for all other particles of SM including Higgs. This will eliminate the above Higgs coupling to ψ as well as the off-diagonal mass terms originally present before symmetry breaking and make ψ absolutely stable. This completes the model based on case (1).

In case (2), there is no need of the discrete symmetry Z_2 . Conservation of the $U(1)$ hypercharge itself forbids the Higgs coupling of ψ as well as the off-diagonal mass terms connecting ψ with the right-handed charged leptons. Thus the doubly charged ψ is automatically stable.

If ψ exists, it will have an important application. Muon catalyzed fusion is a well-studied phenomenon. Negative muons captured in orbits around d-d and d-t nuclei (d = deuteron, t = triton) lead to close approach of the nuclei inducing fusion. But the instability of the muon has so far prevented the practical utilization of this phenomenon. Replacing μ by ψ we gain in two ways: ψ does not decay and further its high mass will lead to tighter orbit and increased probability of nuclear fusion. Is this the explanation for the reported "cold fusion", which is as yet not an established phenomenon?

It is possible that ψ particles produced primordially in the very early Universe are lurking around, waiting to be discovered. In any case, search for ψ and $\bar{\psi}$ produced in LHC and the future linear collider may be worthwhile.

Neutral ψ -onic atoms such as proton + ψ or $He^4 + \psi$ respectively in the case of singly or doubly charged ψ are candidates for dark matter. Such models have been studied extensively by Khlopov and collaborators (1). Variations on this theme have also been proposed. See for instance, Glashow (2).

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References:

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